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TIDE AND SALINITY REGIME ALTERATION IN TWO RIVERINE ESTUARIES ON FLORIDA'S EAST COAST DURING HURRICANES FRANCES AND JEANNE OF 2004

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ABSTRACT

The South Florida Water Management District mission is to manage and protect water resources of the region by balancing and improving water quality, flood control, natural systems and water supply. Hurricanes have a major impact on almost all aspects of our mission. Besides being a major cause of flooding and water supply interruption, hurricanes also affect water quality and the natural systems. The focus of this paper is to examine the impact of two major hurricanes in 2004 on the two coastal water bodies that were in the vicinity of the landfall of Hurricanes Frances and Jeanne in September 2004. A better understanding of how hurricanes affect coastal waters will help increase our predictive capability to enhance and improve water management and restoration of coastal ecosystems. This paper compares tidal and salinity data collected in the Loxahatchee and St. Lucie estuaries located in southeast Florida during Hurricane Frances and Jeanne in September 2004. The Loxahatchee data were collected with five monitoring stations ranging from River Mile 1 to River Mile 9 (the distance from the ocean to the monitoring sites following the center line of the river). The St. Lucie data was collected from two stations, about 5 and 9 river miles away from the ocean. The results showed that Hurricanes Frances and Jeanne caused a water level surge of approximately 0.8 m in the Loxahatchee Estuary and 1.3 m in the St. Lucie Estuary. For the five stations in the Loxahatchee Estuary, the recorded tidal pattern and the magnitude of the tidal surge remained about the same as that upstream in the Northwest Fork of the river. Salinity response to tidal surge varies with stations, depending on the distance away from the ocean and the amount of freshwater inflow coming to the estuary. The two stations in the St. Lucie Estuary recorded a sharp salinity increase corresponding to tidal surge during both of the hurricanes. In the Loxahatchee Estuary, the two stations that were two miles away from the ocean recorded a sharp decrease in salinity during both hurricanes (from about 30-35 ppt to 1-5 ppt) and wide post-hurricane salinity oscillations. The other three stations in the Northwest Fork recorded strong salinity increase in response to the tidal surge induced by Hurricane Frances. Such a salinity spike was not recorded in the two upstream stations during Hurricane Jeanne due to the elevated freshwater flow following Hurricane Frances.

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1. INTRODUCTION

The South Florida Water Management District mission is to manage and protect water resources of the region by balancing and improving water quality, flood control, natural systems and water supply. Hurricanes have a major impact on almost all aspects of our mission. Besides being a major cause of flooding and water supply interruption, hurricanes also affect water quality and the natural systems. The focus of this paper is to examine the impact of two major hurricanes in 2004 on the two coastal water bodies that were in the vicinity of the landfall of Hurricanes Frances and Jeanne in September 2004. A better understanding of how hurricanes affect coastal waters will help increase our predictive capability to enhance and improve water management and restoration of coastal ecosystems.

The St. Lucie and Loxahatchee estuaries are two riverine estuaries on the southeast coast of Florida (Figure 1). The St. Lucie River discharges into the Atlantic Ocean through the St. Lucie Inlet. The Loxahatchee River connects with the Atlantic Ocean at Jupiter Inlet approximately 20 miles south of the St. Lucie Inlet. Both estuaries provide habitats supporting important ecological resources such as seagrasses and oysters.

The South Florida Water Management District (SFWMD) has been working with the United States Geological Survey (USGS) to establish and maintain a tide and salinity monitoring network in the St. Lucie Estuary since 1997. A similar network has been established in the Loxahatchee Estuary since 2002. In 2004, Florida was hit by four major hurricanes (Charley, Frances, Ivan, and Jeanne). Two of them (Frances and Jeanne) made landfall right over the St. Lucie River area and caused substantial damage to both estuaries. Hurricane Frances made landfall on September 5 with maximum sustained winds of 169 km/h (Category 2). Hurricane Jeanne came ashore on September 26 as a category 3 hurricane with maximum sustained winds of 193 km/h. During Hurricanes Frances and Jeanne, most stations of the monitoring network survived the storms and recorded a relatively complete data set.

The objective of this paper is to determine the impact of the hurricanes on the tidal and salinity patterns in the two estuaries. The analysis will provide insight into the characteristics and mechanisms of tidal wave propagation in the two systems. The results will also be useful in future model simulations under extreme weather conditions in this area (Wan and Hu, 2006).

2. MATERIALS AND METHODS

As part of ongoing ecosystem restoration efforts, tide and salinity monitoring devices have been deployed at two sites in the St. Lucie Estuary since August 1997 and at four sites in the Loxahatchee Estuary since November 2002. An additional site was added to the upstream end of the Loxahatchee monitoring network in October 2003. All of the stations record water level, temperature, and salinity continuously every 15 minutes. The two stations in the St. Lucie Estuary are located in the middle of the estuary, about five and nine river miles away from the St Lucie Inlet. The five stations in the Loxahatchee Estuary include two in the central embayment area and three along the Northwest Fork, which is the biggest tributary of the Loxahatchee Estuary. These stations are located at approximately one, two, six, eight and nine river miles away from the Jupiter Inlet. For discussion purpose, the stations are named SLE-5 and SLE-9 for the St. Lucie Estuary and LE-1, LE-2, LE-6, LE-8, LE-9 for the Loxahatchee Estuary as shown in Figure 1. The number refers to the approximate river miles away from the ocean.

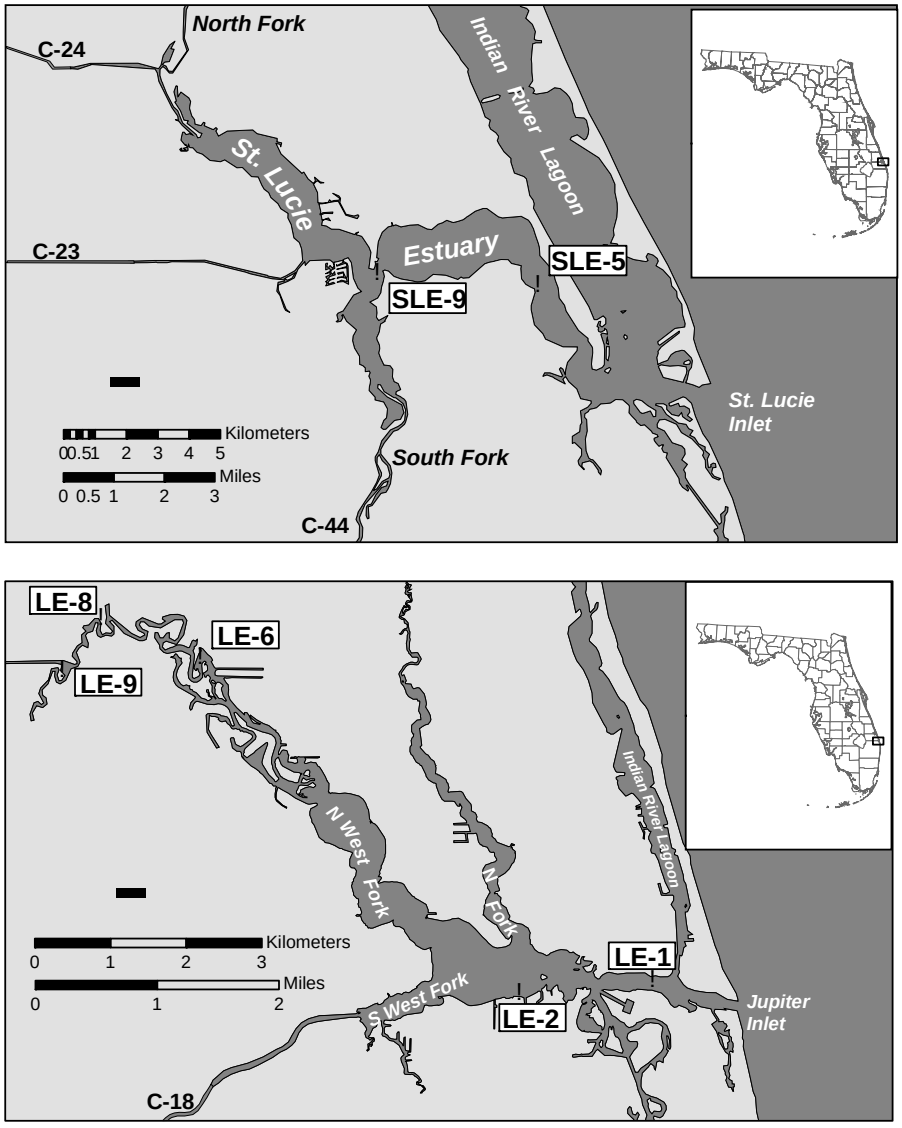

Figure 1 Location map.

Freshwater flow rates into the St. Lucie Estuary are measured at three discharge structures on canals C-23, C-24 and C-44 which account for about 70% of freshwater inflows into the St. Lucie Estuary. Freshwater inflows into the Loxahatchee Estuary are measured at two major tributaries of the estuary, Northwest Fork and Southwest Fork with four flow stations. The Northwest Fork contains a 9-mile federally-designated Wild and Scenic River. The Southwest Fork receives flows through a gated water control structure called S-46, discharging directly into the central embayment of the Loxahatchee Estuary. These stations capture flow from about 80% of the entire watershed discharging into the Loxahatchee Estuary (Wan and Hu, 2006). Quality assurance and quality control (QA/QC) has been conducted with all data analyzed in this study.

3. RESULTS AND DISCUSSION

Figure 2 shows the water surface elevation (WSE) and salinity data recorded during September 2004 from stations LE-1 and LE-2, which are about 1 and 2 river miles away from the ocean, respectively. The change in WSE for the two stations is almost identical. Water level surged by about 0.8 m when Hurricane Frances made landfall 20 miles to the north. The surge on September 26 during the landfall of Hurricane Jeanne is at about the same level in spite of a stronger hurricane. It is interesting to note that before Hurricane Jeanne made landfall, tide started to surge on September 21 and this surge was maintained until September 26. This is probably because during the week of September 19 Tropical Storm Jeanne looped around in the Atlantic Ocean, became a hurricane on September 21, and finally moved towards east coast of Florida prior to its landfall on September 26.

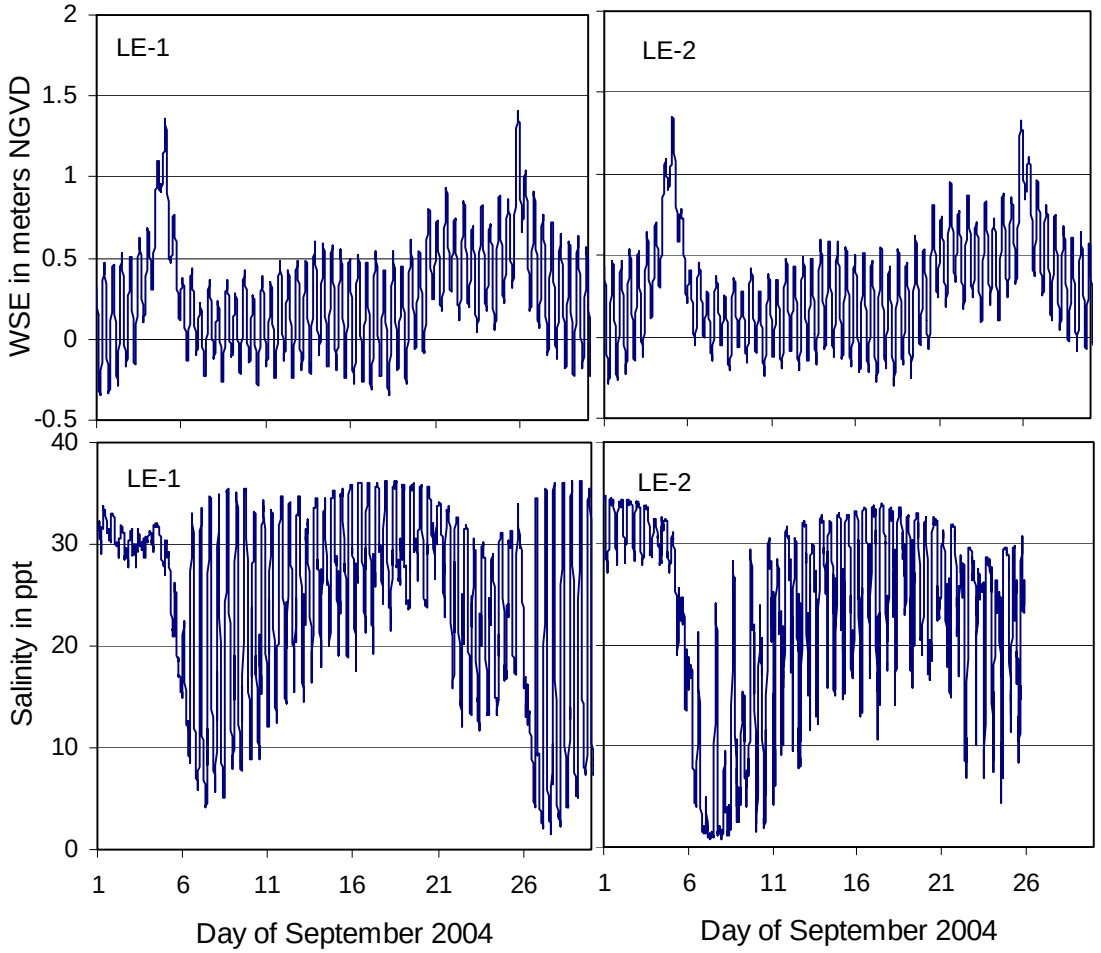

Figure 2 Tide and salinity in Loxahatchee Estuary.

The salinity record at both stations shows a rapid decline following hurricanes. For example, minimum salinity at Station LE-1 reached about 5 and 2 ppt after Hurricanes Frances and Jeanne, respectively. This is mostly due to the heavy rainfall and high freshwater flow coming into the estuary with the hurricanes. Freshwater inflows from the Northwest Fork and Southwest Fork into the Loxahatchee Estuary are shown in Figure 3. It was indicated that prior to Hurricane Frances, there were a sustained period of low flow (<10 cubic meter per second) coming into the Loxahatchee Estuary. Discharge from S-46 into the Southwest Fork was virtually zero prior to the storms.

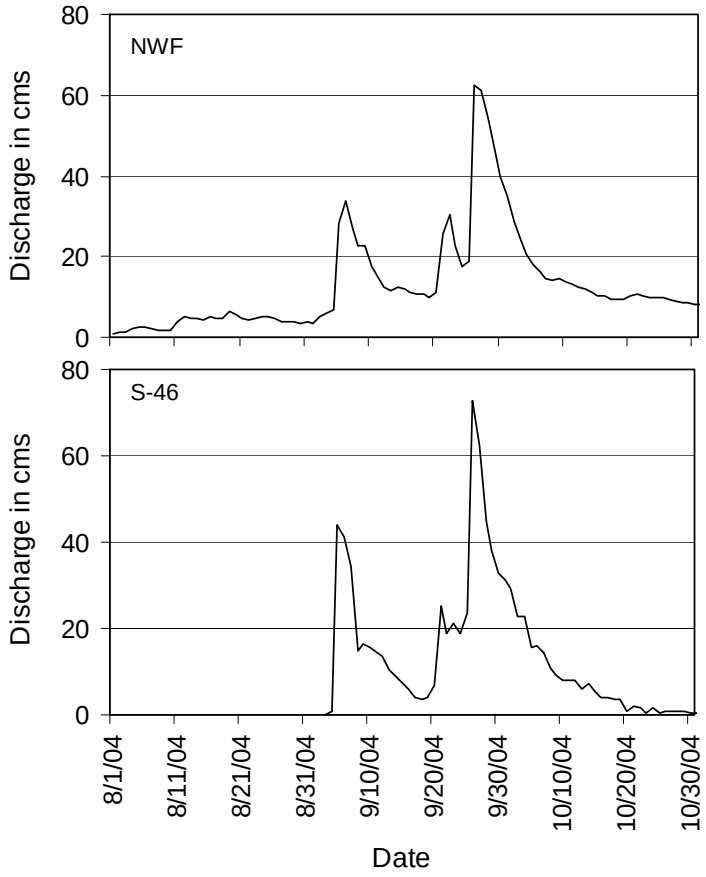

Figure 3 Freshwater flow into Loxahatchee Estuary through the Northwest Fork (NWF) and through the Southwest Fork from drainage structure S-46.

The Northwest Fork inflow reached 33.6 cubic meter per second (cms), which is 1188 cubic feet per second (cfs) during Hurricane Frances and 62.6 cms (2211 cfs) during Hurricane Jeanne. The corresponding peak discharge from S-46 was 43.9 cms (1551 cfs) and 72.9 cms (2204 cfs), respectively. After the storm, salinity recovered to the 30 ppt level approximately a week later at Station LE-2 and 2 days later at Station LE-1. The difference of salinity between the two stations manifests their proximity to the ocean. The salinity oscillation during a tide cycle remained to be much bigger than that prior to Hurricane Frances.

The WSE and salinity data recorded by Stations LE-6, LE-8, and LE-9 are depicted in Figure 4. These stations are located within the upper Northwest Fork in contrast to LE-1 and LE-2 which are much closer to the ocean. It is interesting to note that the overall tidal pattern and the magnitude of tidal surge in the upper Northwest Fork recorded by these stations are about the same with these in the embayment area when compared with Figure 2. Water level raised by nearly 0.9 m at all three sites during the landfall of Frances and about 0.8 m during Jeanne.

In spite of the similarity in the tidal amplitude, the salinity regime in the Northwest Fork differed significantly from that in the embayment area. Because the tidal surge may bring a large mass of water with high salt content into the upper Northwest Fork, a sharp salinity increase was observed at River Mile 6 during both hurricanes. Salinity at this site reached 24 ppt during the first storm and increased from near 0 to 15 ppt during the second storm. The salinity increase due to saltwater intrusion up the estuary was also observed in the Chesapeake Bay during Hurricane Isabel (Boicourt, 2005; Brasseur et al, 2005). The sustained tidal impact prior to the landfall of Hurricane

Jeanne created salinity oscillation ranging from about 1 to as high as 18 ppt for three days in spite of high rainfall and increased freshwater inflow. However, for Stations LE-8 and LE-9 such salinity spikes were observed only during Hurricane Frances but not during Hurricane Jeanne. This is possibly due to the fact that freshwater inflow into the Northwest Fork prior to and during Hurricane Jeanne was much larger than that for Hurricane Frances (Figure 3). As a result, the salt wedge was impeded by the large amount of freshwater flow.

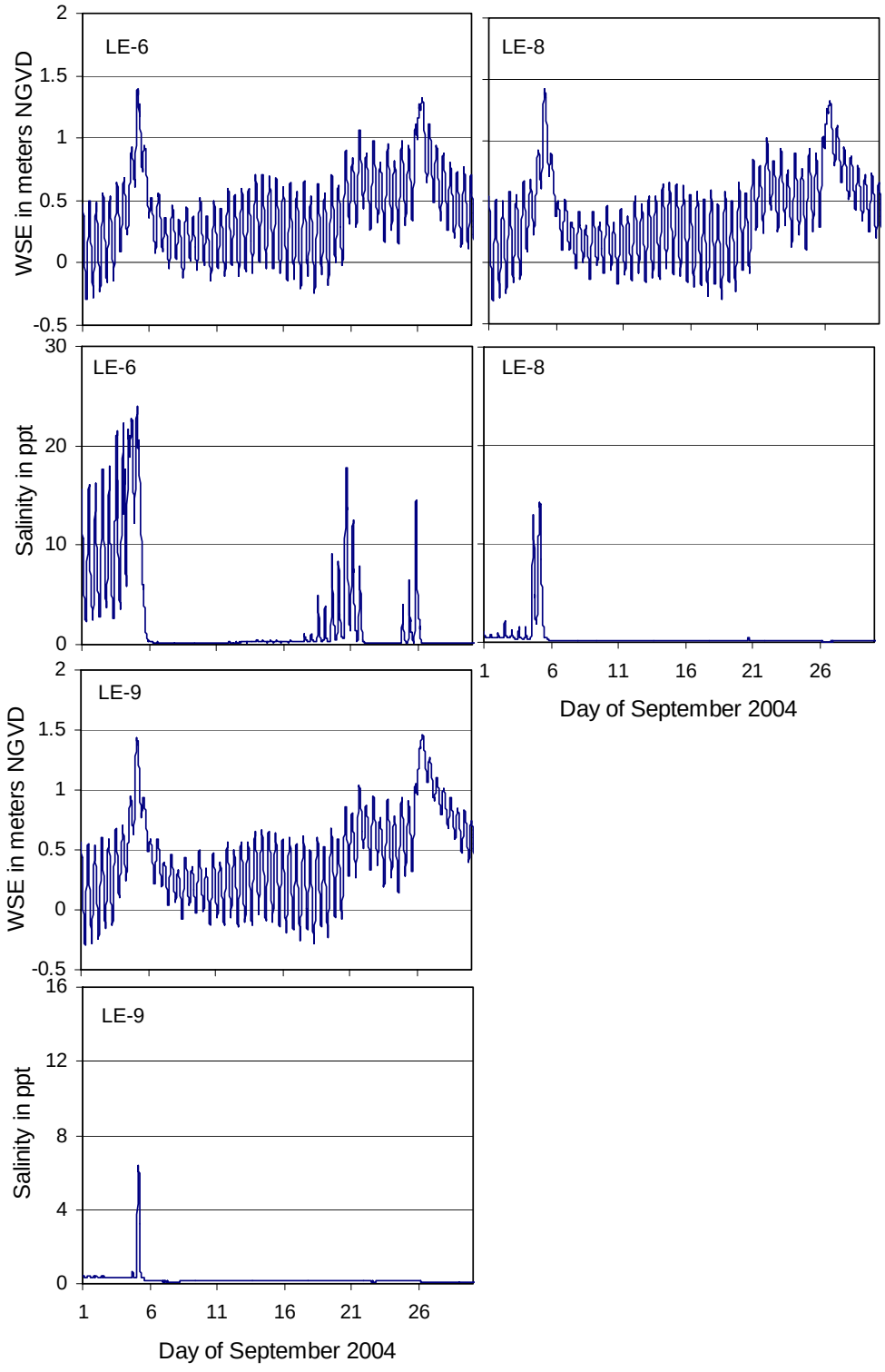

Figure 4 Tide and salinity in the upper Northwest Fork of Loxahatchee River.

The two monitoring stations in the St. Lucie Estuary are 5 and 9 miles away from the St. Lucie Inlet, respectively. The water level reached 1.6 m above zero NGVD at both sites during the two hurricanes with a magnitude of water level surge of approximately 1.2 to 1.4 m (Figure 5). The larger tidal surge is indicative of the stronger wind and wave actions in the St. Lucie area than for Loxahatchee due to its proximity to the center of the two hurricanes. Hurricane Jeanne created about 0.5 m tidal surge in the St. Lucie Estuary prior to its landfall as well. The salinity response to these surges is also similar to that in the Loxahatchee Estuary. For example, at Station SLE-9 a sharp salinity increase by 10 to 15 ppt was recorded during Hurricane Frances, while such salinity increases becomes less in magnitude when Jeanne came 20 days later (Figure 5). The overall change of salinity in the St. Lucie Estuary in response to the hurricanes and tide was also consistent with that of freshwater inflow.

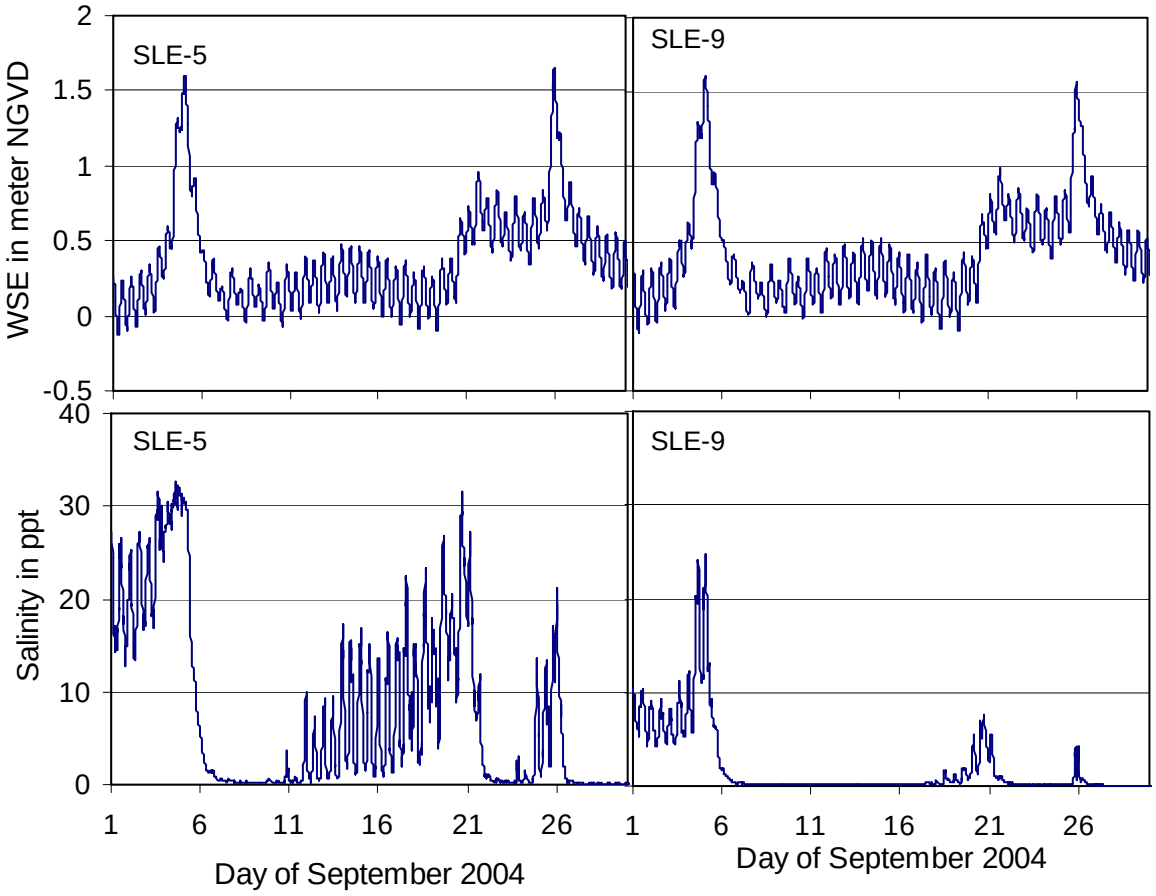

Figure 5 Tide and Salinity in the St. Lucie Estuary.

Figure 6 is the combined discharge from three major canals into the St. Lucie Estuary. The discharge increased by about 10 fold during the two hurricanes in September. Peak discharge was 301.1 cms (10639 cfs) during Hurricane Frances and 441.7 cms (15609 cfs) during Hurricane Jeanne. Sustained high flow following the hurricanes creates a low salinity regime that is harmful for oysters in the embayment and seagrasses in the downstream area.

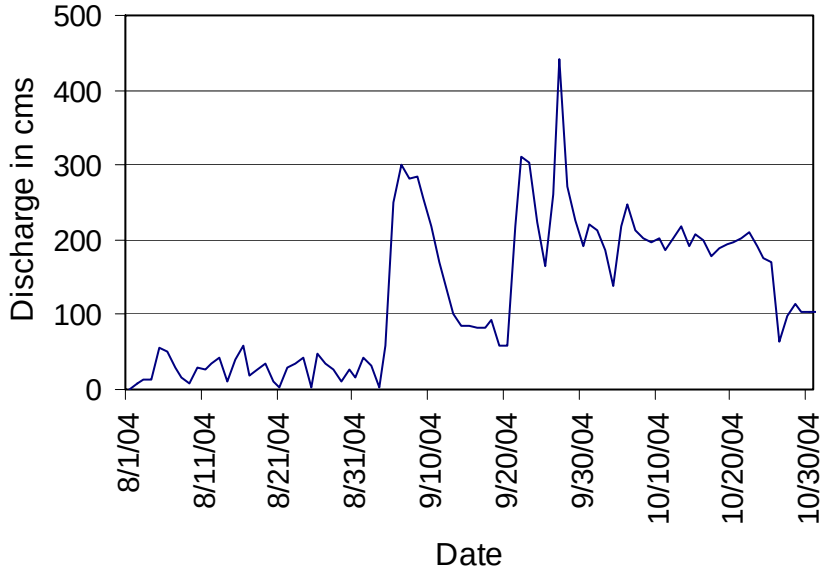

Figure 6 Freshwater flow into the St. Lucie Estuary.

It is interesting to note that SLE-9 and LE-9 are located at about the same river miles away from the ocean, but LE-9 recorded much lower salinity than SLE-9. This is indicative of the influence of the physical geometry of the estuary on the salt water transport. Station SLE-9 is located at the confluence of two tributary forks of the St. Lucie Estuary with wide opening towards the embayment area. Station LE-9 is located in the middle of Northwest Fork. The meandering nature of the Northwest Fork provides a much higher degree of hydraulic resistance to saltwater intrusion than for the St. Lucie Estuary. The high hydraulic resistance of Northwest Fork to salt water movement is also reported by Russell and McPherson (1984) and Hu (2004).

4. CONCLUSIONS

This study compares tidal and salinity data collected during Hurricanes France and Jeanne in 2004 in the Loxahatchee and St Lucie Estuaries, located on the southeast coast of Florida. Both hurricanes resulted in water level surge for about 0.8 m in the Loxahatchee Estuary and 1.3 m the St. Lucie Estuary. For the 5 stations in the Loxahatchee Estuary extending about 9 river miles away from the ocean, the recorded tidal pattern and the magnitude of the tidal surge is similar between the stations.

The salinity response to the tidal surge varies with stations, depending on the distance away from the ocean and the amount of freshwater inflow coming to the estuary. For the Loxahatchee Estuary, the two stations within 2 miles away from the ocean recorded a sharp decrease in salinity during the hurricane (from about 30-35 ppt to 1-5 ppt) and wide salinity oscillations after the hurricanes. All the three stations in the Northwest Fork recorded strong salinity increase in response to the tidal surge induced by Hurricane Frances. Such a salinity spike, though smaller in magnitude, was recorded only at LE-6 during Hurricane Jeanne due to the elevated freshwater flow following Hurricane Frances. The pattern of salinity surge during hurricanes and salinity decrease after the hurricane were also recorded by the two stations in the St. Lucie Estuary.

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